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Technologies of Strategic Importance Associated with the Mobile Servicing System

Canada

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TECHNOLOGIES OF STRATEGIC IMPORTANCE ASSOCIATED WITH THE MOBILE SERVICING SYSTEM

Prepared by the

Advanced Technology Subcommittee

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Ce rapport est disponible en français

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PREFACE

The Advanced Technology Subcommittee reports to the Space Station Working Group. The Subcommittee was established in April, 1986, with the following mandate:

- Propose strategies and methods to improve the status of advanced technologies in Canada through the Space Station Program;
- Propose strategies and methods to maximize benefits from Space Station advanced technology developments;
- Propose specific areas of technology which should be focal point of Canadian activity;
- Assess Canadian status and progress concerning Space Station related advanced technologies. Identify strengths and weaknesses.
- Review role of international cooperation for technology development.

The Subcommittee concentrates its activities on technologies associated with the Mobile Servicing System at present. Technologies associated with Life Sciences, Material Processing, Science, Communications, Remote Sensing, Users, and Operations, are addressed in other parallel Subcommittees.

The membership of the Advanced Technology Subcommittee is given below.

Dr. S. Karius	NRC	Chairman (pre Nov. 1986)	
Mr. H. Werstiuk	NRC	Chairman (post Nov. 1986)	
Mr. B.V. Tryggvason	NRC	Secretary	
Mr. S. Sachdev	SPAR	Member	
Dr. P.C. Hughes	UTIAS & DYNACON	Member	
Dr. F.R. Vigneron	DOC	Member	
Mr. R. Swann	MDA	Member	
Mr. V. Nijhawan	CAL	Member	
Mr. J. Arkwright	DND	Member	
Mr. D. Caswell	NRC	Member	(post Nov. 1986)
Mr. R.M. Vaive	MOSST	Observer	
Mr. J. Boulakia	DRIE	Observer	
Dr. V. Sulway	NRC/IRAP	Observer	
Dr. I.H. Rowe	SPAR	Observer	

SUMMARY

This report describes an activity undertaken in the period September to December 1986 by the Advanced Technology Subcommittee of the Space Station, with the goal of recommending which of the technologies of the Mobile Servicing Systems (MSS) of the Space Station are of strategic importance to Canada.

All of the technologies known at this stage to be needed for the MSS are first identified. An analysis done by the Subcommittee members is then described, in which criteria for strategic importance are given and the technologies are examined relative to the criteria. A survey of the views of industry is described and discussed. The Subcommittee's analysis and the results of the industry survey are then combined to obtain a Subcommittee consensus regarding the MSS technologies of strategic importance.

The technologies of Teleoperation and Robotics (Vision Systems, Sensors, Robot Programming, Human-machine Interfaces/Telepresence, Manipulator Analysis, Manipulator Control, Simulators, Robot Mechanisms), Automation of Operations (Expert Systems in Operations, Automated Data Management, Automated Power Management), Processor Systems and Interprocessor Communications, Materials and Automated Test Equipment are identified as MSS technologies of strategic importance.

In addition, the following technologies were not adequately addressed in the industry survey, but were identified by the Subcommittee as being of possible strategic importance: Power Systems; Qualification Strategies; Lubrication in Space; and Software Development and Verification. Certain technologies of the MSS do not meet the strategic classification but nevertheless are necessary for the MSS and may require a significant level of directed technology development in Canada. Included in this category are Environmental Effects and Integration and Test.

1. INTRODUCTION

At the September 18/86 meeting of the Subcommittee, Dr. K.H. Doetsch noted the intent of the Program to prepare a Strategic Plan for Advanced Technology Development for Space Station. The Subcommittee agreed to make a preliminary identification of the strategic technologies of the Mobile Servicing System (MSS) in support of the Strategic Plan.

This report contains the preliminary identification of the MSS technologies of strategic importance.

The Committee has not had time to discuss the subject thoroughly with all industries and agencies, particularly as regards spin-off possibilities. Also, the Space Station configuration and the MSS requirements are still evolving. Thus the identification of strategic technologies is preliminary, and subject to revision.

In this report, all of the technologies known at this stage to be needed for the initial and evolutionary configurations of the MSS are first identified. Then an analysis done by the Subcommittee members is described, in which criteria for strategic importance are given and the technologies are examined relative to them. The results of a limited survey by questionnaire of the views of industry regarding the MSS technologies is presented and discussed. The Subcommittee's analysis and the industry survey are then combined to arrive at the Subcommittee's present consensus regarding technologies of strategic importance.

2. TECHNOLOGIES OF THE MOBILE SERVICING SYSTEM (MSS)

The technologies involved in the design and development of the MSS, as compiled and categorized by the Subcommittee, are listed below. The MSS and its technologies are described in Appendix A.

TELEOPERATION AND ROBOTICS
- Vision Systems
- Sensors
- Robot Programming
- Human-Machine Interfaces/Telepresence
- Manipulator Analysis
- Manipulator Control
- Simulators
- Robot Mechanisms

AUTOMATION OF OPERATIONS
- Expert systems in Operations
- Automated Data Management
- Automated Power Management

ELECTRICAL AND ELECTRONICS
- Processor Systems and Interprocessor Communications
- Communications
- Power Systems

STRUCTURES AND MATERIALS
- Structural Design
- Lubrication in Space
- Materials
- Thermal Control
- Environmental Effects

VERIFICATION
- Qualification Strategies
- Reliability and Quality Assurance
- Integration and Test
- Automated Test Equipment
- Software Development and Verification

3. ANALYSIS BY SUBCOMMITTEE MEMBERS

The Subcommittee has representation from key industries and agencies involved in the Space activity in Canada, and thus the members are able to offer a view of the importance of the various technologies. An analysis done by the members is described in this chapter.

3.1 Criteria for MSS Technologies of Strategic Importance

The Subcommittee has adopted the following definition of 'strategic importance;

To be considered of strategic importance to Canada as regards the MSS, a particular technology must meet all the following criteria:

(1) Be of potential use in the design and development of Canada's part of the basic MSS, and/or the evolutionary MSS;

(2) Be a new technology in Canada, or require a substantial upgrade of an existing Canadian capability to achieve a technological advantage;

(3) Be technically and economically feasible to develop in Canada, as opposed to purchase off-shore;

(4) Have spin-off possibilities into other space or terrestrial applications.

3.2 Consideration of MSS Technologies Relative to Criteria

The technologies of the MSS as identified in Chapter 2 are considered relative to the criteria set forth in Section 3.1, and are presented in the right hand column of Table 1. The assessment was done on the basis of the experience and background of the Subcommittee members.

The technologies associated with **TELEOPERATION AND ROBOTICS** all appear to meet the criteria. The technologies are virtually all involved in both the basic and the evolutionary MSS, and are generally new technology development areas.

In the **AUTOMATION OF OPERATIONS** area, **Expert Systems in Operation** meets the criteria. As regards **Automated Data Management**, although NASA may design and specify much of the system there is nevertheless felt to be scope for significant development specific to the MSS. **Automated Power Management** is important because power is identified as an extremely valuable resource on the Space Station. As NASA plans to automate the overall power management through a combination of conventional and AI techniques, there is a significant incentive and opportunity for corresponding technology in MSS. The technology has potential spin-offs for power management of other space systems (communications and earth resources satellites) and for terrestrial power systems and hydro grids.

In the **ELECTRICAL & ELECTRONICS** area, **Power Systems** appear to meet the criteria for strategic importance; there are many specialized components to be developed, and many companies in Canada that are capable of capitalizing on such development. Long-life battery development in Canada might be marginal because of the high cost/low spin-off potential. The **Communications System** is likely to be standard technology and not require significant technology development. **Processor Systems and Interprocessor Communications** presents opportunities for development, especially in software engineering, distributed processing, and fault tolerant computing. It is not clear at this stage that it is economically reasonable to develop hardware processors in Canada, owing to the lead in this area by Japan and the USA.

In the **STRUCTURES AND MATERIALS** area, **Lubrication in Space** and **Materials** appear to meet the criteria and both will be needed for the basic MSS. No significant advance in technology appears needed for **Structural Design** and **Thermal Control. Environmental Effects** are important (especially atomic oxygen), but is is not obvious there are significant spin-offs.

As regards **VERIFICATION**, the **Automated Test Equipment** area appears to meet the criteria; the spin-offs envisaged are space contracts at the subsystem and system level or component/system products. **Qualification Strategies** and **Software Development and Verification** are necessary in the MSS and feasible to develop in Canada. It further appears to be the view of

some space industries that competence in these areas is key to credibility as regards space and the sophisticated terrestrial spin-offs, and hence these technologies are judged to be of strategic importance. **Integration** and **Test** is a necessary technology for the MSS, but significant spin-off potential has yet to be established. **Reliability and Quality Assurance** is also critical for the MSS, but it is not clear that a significant upgrade in capability is needed.

From Table 1, it is evident that the following MSS technologies meet the criteria identified in Section 3.1, and are thus potentially of strategic importance.

TELEOPERATION AND ROBOTICS
- Vision Systems
- Sensors
- Robot Programming
- Human-Machine Interfaces/Telepresence
- Manipulator Analysis
- Manipulator Control
- Simulators
- Robot Mechanisms

AUTOMATION OF OPERATIONS
- Automated Data Management
- Expert Systems in Operations
- Automated Power Management

ELECTRICAL AND ELECTRONICS
- Processor Systems and Interprocessor Communications
- Power Systems

STRUCTURES AND MATERIALS
- Lubrication in Space
- Materials

VERIFICATION
- Qualification Strategies
- Automated Test Equipment
- Software Development and Verification

TABLE 1 - CONSIDERATION OF TECHNOLOGIES RELATIVE TO CRITERIA

	In Basic MSS	In Evolutionary MSS	New or Require Upgrade	Feasible to Develop in Canada	Spin-offs Likely
TELEOPERATION AND ROBOTICS					
Vision Systems	X	X	U,N	X	X
Sensors	X	X	U,N	X	X
Robot Programming	X	X	N	X	X
Human-Machine Interfaces/Telepresence	X	X	U,N	X	X
Manipulator Analysis	X		U	X	X
Manipulator Control	X	X	U,N	X	X
Simulators	X	X	U	X	X
Robot Mechanisms	X	X	U,N	X	X
AUTOMATION OF OPERATIONS					
Expert Systems in Operations	X	X	N	X	X
Automated Data Management	X		U	X	X
Automated Power Management	X	X	U	X	X
ELECTRICAL AND ELECTRONICS					
Processor Systems and Interprocessor Communications	X	X	U,N	X	X
Communications	X			N/A	N/A
Power Systems	X		U	X	X
STRUCTURES AND MATERIALS					
Structural Design	X			N/A	N/A
Lubrication in Space	X		U	X	X
Materials	X		U	X	X
Thermal Control	X			N/A	N/A
Environmental Effects	X		U	X	?
VERIFICATION					
Qualification Strategies	X	X	U	X	X
Reliability and Quality Assurance	X	X	?	?	?
Integration and Test	X	?	U	X	?
Automated Test Equipment	X	X	N	X	X
Software Development and Verification	X	X	U	X	X

4. INDUSTRY SURVEY

The questionnaire presented in Appendix B was sent to the 98 Canadian aerospace-related companies listed in Appendix C to obtain industry views and interest as regards the MSS technologies. Forty-nine responses were received of which 39 were included in the analysis which follows. Those excluded from the analysis were either duplicate responses from the same company (4), or from companies that indicated no interest in any of the technologies or returned Part 1 of the questionnaire unanswered (6).

Part 1 of the Questionnaire was concerned with industry views on development of 21 specific technologies (the list of specific technologies is slightly different than that presented in Chapter 2 of this report, however, the relationship between the two lists is given in Chapter 5, Tables 6 and 7).

Table 2 gives a summary of the base responses to Part 1 of the questionnaire, obtained by totalling the number of responses in each square. It is difficult to interpret Table 2 directly, because a negative response cannot be distinguished from a neutral or no interest indication. However, two rankings can be confidently derived from the base information of Table 2; "level of interest based on company perspective" and "perceived importance of technologies to Canada".

The ranking of "level of interest based on company perspective" is derived from the responses to the first three columns of Table 2, and is given in the first column of Table 3. The ranking of "perceived importance of technologies to Canada" is derived from the responses of the latter three columns of Table 2, and is given in the second column of Table 3. The point rating in both cases presented in Table 3 is a weighted sum of the columns identified above from Table 2 and is normalized so that all responses lie between 0 and 100.

The order of importance is similar in the two columns in Table 3. Different weightings were also explored, and the basic ratings were found to

be relatively insensitive to them. The two rankings of Table 3 were then further combined by averaging to obtain the combined ranking of industry interest and importance given in Table 4. These scores were also noted to be clustered into six groups, as shown in Table 4.

The level of response by industry to the questionnaire (49 responses our of 98 questionnaires mailed) was high, and indicates an overall enthusiasm for the technologies of the Space Station MSS. Table 4 further indicates a considerable interest to industry in automation and robotics technologies, and in particular, to Vision Systems and Expert Systems. The latter two technologies are also noted to be the subjects of assessment by the Department of Regional and Industrial Expansion (DRIE).

The comments obtained in response to Part II - Technology Transfer are summarized in Table 5. Many of the comments are peripheral to the main subject of this report (identification of strategic technologies), but are welcomed useful information for other present and future activities of the Subcommittee. The comments should not be interpreted as official opinions of the Subcommittee at this time.

TABLE 2 - TOTAL NUMBER OF RESPONSES TO EACH SQUARE OF THE QUESTIONNAIRE

IRRELEVANT TO MY ORGANIZATION	OF INTEREST TO MY ORGANIZATION	CRITICAL TO MY ORGANIZATION	CANADA AT WORLD STANDARD	CAN FORESEE RAPID EVOLUTION	CRITICAL TO CANADA	
23	12	1	7	7	7	Astronaut Training
16	18	8	6	17	17	Automated Data Management
18	15	1	6	12	10	Automated Power Management
13	10	8	5	17	12	Automated Test Equipment
11	17	10	3	23	19	Expert Systems
26	3	2	6	3	3	Long-Life Brake/Clutch Materials
26	5	2	4	5	4	Long-Life Lubrication
22	8	4	12	11	8	Manipulator Analysis
21	10	4	16	12	10	Manipulator Control
15	13	10	4	21	17	Man-Machine Interfaces
14	7	6	2	15	12	Materials & Structures
14	11	4	3	10	6	Mission Operations
13	14	10	6	17	13	Processors & Data Busses
20	12	2	6	6	6	Qualification(Incl. In-Orbit Test)
17	6	3	4	18	16	Robot Programming
9	17	8	3	18	17	Sensors
17	14	7	7	15	13	Simulators
18	12	5	3	19	11	"Smart" Mechanisms
22	9	2	3	8	5	Thermal Control
22	7	3	3	9	7	Tools & End Effectors
11	17	10	6	23	16	Vision Systems
A	B	C	D	E	F	

TABLE 3 - RANKINGS FROM INDUSTRY SURVEY

"LEVEL OF INTEREST BASED ON COMPANY PERSPECTIVE" Normalized Sum (-A+B+2C)		"PERCEIVED IMPORTANCE OF TECHNOLOGIES TO CANADA" Normalized Sum (D+3E+2F)	
Vision Systems	55	Expert Systems	46
Expert Systems	55	Vision Systems	45
Sensors	53	Automated Data Management	43
Processors & Data Busses	51	Man-Machine Interfaces	42
Automated Test Equipment	49	Sensors	38
Man-Machine Interfaces	48	Robot Programming	38
Automated Data Management	48	Processors and Data Busses	35
Simulators	43	Smart Mechanisms	34
Robot Programming	38	Automated Test Equipment	33
Smart Mechanisms	37	Simulators	33
Materials & Structures	33	Materials & Structures	30
Automated Power Management	33	Manipulator Control	30
Mission Operations	33	Automated Power Management	26
Manipulator Control	31	Manipulator Analysis	25
Qualification	30	Mission Operations	19
Manipulator Analysis	28	Tools and End Effectors	18
Astronaut Training	26	Astronaut Training	18
Tools & End Effectors	26	Thermal Control	15
Thermal Control	26	Qualification	15
Long Life Lubricants	19	Long Life Lubricants	11
Long Life Brake/Clutch Mat.	18	Long Life Brake/Clutch Mat.	9

TABLE 4 - COMBINED RANKING OF INDUSTRY INTEREST AND IMPORTANCE

(51-52)	Group I	Expert Systems Vision Systems
(41-46)	Group II	Automated Data Management Sensors Man-Machine Interfaces Processors and Data Busses Automated Test Equipment
(36-38)	Group III	Robot Programming Simulators Smart Mechanisms
(26-32)	Group IV	Materials and Structures Manipulator Control Automated Power Management Manipulator Analysis Mission Operations
(21-23)	Group V	Qualification Astronaut Training Tools and End Effectors Thermal Control
(14-15)	Group VI	Long Life Lubricants Long Life Brake/Clutch Materials

TABLE 5 - INDUSTRY COMMENTS* ON TECHNOLOGY TRANSFER

(From Part II of Questionnaire)

1. Protection of rights is a major issue. Need to control transfer of data.

2. In the short term the Space Station Program must be managed to ensure hardware delivery.

   In the long term the technologies must be effectively used by Canadian Industry.

   To address the above, the Space Station Program Office should separate the responsibilities.

3. Contracts to industry seem the most effective means of technology transfer.

4. - There is a problem in getting reasonable subcontracting. Method of awarding subcontracts needs to be better defined.

   - Should allow subcontracts outside Canada

5. - Need for better access to information on standards, specifications and bidding procedure as regards ESA and NASA.

   - Need information on the organizational structures of Space Station Program.

   - Need better NRC representation in British Columbia.

6. Section on National Importance biased to 'yes' answers.

7. - Most important aspect of Space Station Program is Polar Platform, and priority should be given to it.

   - Remote Sensing should be included.

* These comments should not be interpreted as an official opinion of the Advanced Technology Subcommittee.

5. STRATEGIC TECHNOLOGIES

The results of the assessment by the Subcommittee (Chapter 3) and those of the industry questionnaire (Chapter 4) were further combined, in a manner described in this chapter, to arrive at a designation for each technology.

The list of the MSS Technologies presented in Chapter 2 evolved over a period of two months from the list contained in the Industry Questionnaire, the former being the more complete. The correspondence between the two lists is given in Table 6.

Table 7 shows the assessments side-by-side, and further indicates the resulting designation. The 'Strategic' designation was given to technologies that were deemed important by the Subcommittee members, and that ranked in Group 4 or higher in the Industry Survey. The 'Possibly Strategic' designation was given to technologies that were not specifically addressed or that were ranked low in the industry survey but were deemed important by the Subcommittee. The remaining technologies were designated 'not strategic'.

The three categories are further tabulated in Tables 8a and 8b.

Certain technologies do not meet the 'Strategic' classification, but nevertheless are necessary for the MSS and may require a significant level of directed technology development in Canada. Technologies in this category are **Environmental Effects** and **Integration and Test.**

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   In the long term the technologies must be effectively used by Canadian Industry.

   To address the above, the Space Station Program Office should separate the responsibilities.

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4. - There is a problem in getting reasonable subcontracting. Method of awarding subcontracts needs to be better defined.

   - Should allow subcontracts outside Canada

5. - Need for better access to information on standards, specifications and bidding procedure as regards ESA and NASA.

   - Need information on the organizational structures of Space Station Program.

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The three categories are further tabulated in Tables 8a and 8b.

Certain technologies do not meet the 'Strategic' classification, but nevertheless are necessary for the MSS and may require a significant level of directed technology development in Canada. Technologies in this category are **Environmental Effects** and **Integration and Test.**

TABLE 6 - CORRESPONDANCE BETWEEN TECHNOLOGIES OF INDUSTRY QUESTIONNAIRE AND LIST OF MSS TECHNOLOGIES

INDUSTRY QUESTIONNAIRE Oct 1, 1986	MSS TECHNOLOGIES LIST Nov 30, 1986
	TELEOPERATION AND ROBOTICS
Vision Systems	Vision Systems
Sensors	Sensors
Robot Programming	Robot Programming
Man-Machine Interfaces	Human-Machine Interfaces/Telepresence
Manipulator Analysis	Manipulator Analysis
Manipulator Control	Manipulator Control
Simulators, Astronaut Training	Simulators
Smart Mechanisms, Tools and End Effectors	Robot Mechanisms
	AUTOMATION OF OPERATIONS
Expert Systems, Mission Operations	Expert Systems in Operations
Automated Data Management	Automated Data Management
Automated Power Management	Automated Power Management
	ELECTRICAL AND ELECTRONICS
Processors and Data Busses	Processor Systems and Interprocessor Communications
	Power Systems
	STRUCTURES AND MATERIALS
Long Life Lubrication, Long Life Brake & Clutch Materials, Materials and Structures	Lubrication in Space, Materials
Thermal Control	Thermal Control
	Structural Design
	Environmental Effects
	VERIFICATION
Qualification (Incl. In-Orbit Test)	Qualification Strategies
Automated Test Equipment	Automated Test Equipment
	Reliability and Quality Assurance
	Integration and Test
	Software Development and Verification

TABLE 7 - COMBINATION OF SUBCOMMITTEE MEMBER'S VIEW AND INDUSTRY QUESTIONNAIRE

INDUSTRY INTEREST/IMPORTANCE RANKING		SUBCOMMITTEE - GENERATED LIST	DESIGNATION
(51-52)	Expert Systems	Expert Systems in Operations	Strategic
	Vision Systems	Vision Systems	Strategic
(41-46)	Automated Data Management	Automated Data Management	Strategic
	Sensors	Sensors	Strategic
	Man-Machine Interfaces	Human-Machine Interfaces	Strategic
	Processors and Data Busses	Processor Systems etc.	Strategic
	Automated Test Equipment	Automated Test Equipment	Strategic
(36-38)	Robot Programming	Robot Programming	Strategic
	Simulators	Simulators	Strategic
	Smart Mechanisms	Robot Mechanisms	Strategic
(26-32)	Materials and Structures	Materials	Strategic
	Manipulator Control	Manipulator Control	Strategic
	Automated Power Management	Automated Power Management	Strategic
	Manipulator Analysis	Manipulator Analysis	Strategic
	Mission Operations	(Expert Systems in Operations)	N/A
(21-23)	Qualification	Qualification Strategies	Possibly Strategic
	Astronaut Training	(Simulators)	N/A
	Tools and End Effectors	(Robot Mechanisms)	N/A
	Thermal Control		Not Strategic
(14-15)	Long Life Lubricants	Lubrication in Space	Possibly Strategic
	Long Life Brake/Clutch Materials	(Materials)	N/A
		Power Systems	Possibly Strategic
		Software Development and Verification	Possibly Strategic

TABLE 8 (a) - TECHNOLOGIES OF STRATEGIC IMPORTANCE

TELEOPERATION AND ROBOTICS
- Vision Systems
- Sensors
- Robot Programming
- Human-Machine Interfaces/Telepresence
- Manipulator Analysis
- Manipulator Control
- Simulators
- Robot Mechanisms

AUTOMATION OF OPERATIONS
- Automated Data Management
- Expert Systems in Operations
- Automated Power Management

ELECTRICAL AND ELECTRONICS
- Processor Systems and Interprocessor Communications

STRUCTURES AND MATERIALS
- Materials

VERIFICATION
- Automated Test Equipment

TABLE 8 (b) - TECHNOLOGIES OF POSSIBLE STRATEGIC IMPORTANCE

- Power Systems
- Lubrication In Space
- Qualification Strategies
- Software Development And Verification

6. CONCLUDING REMARKS

The foregoing consensus on strategic technologies must be regarded as preliminary, as limited time was available for discussion with industries and agencies, and the questionnaire, which was prepared and distributed in a very short period of time, has some limitations.

The most significant limitation of the questionnaire was that its distribution was limited largely to aerospace-related companies. The committee is aware that many of the MSS technologies are of relevance to other industry sectors and that the value of the questionnaire may be greatly enhanced by a much broader distribution. A further limitation of the questionnaire was that its design made it difficult to derive an interpretation from the responses other than the rather limited rankings as was done in this report.

The Subcommittee will be considering avenues for broadening industrial and university participation in obtaining effective strategies for increasing Canada's benefits from the Space Station Program. The Subcommittee welcomes comments on this report and suggestions for further work.

APPENDIX A

TECHNOLOGIES IN THE MOBILE SERVICING SYSTEM (MSS)

The Mobile Servicing System (MSS) will be the Canadian contribution to the Space Station. The Space Station is an international program, with NASA of the USA as the lead agency, and MOSST, NASDA, and ESA as the participating agencies of Canada, Japan, and Europe, respectively. The Space Station is to be assembled in-orbit with a series of launches beginning in 1993. A basic capability, the Initial Operating Capability (IOC), will first be established, which will be somewhat limited due to time and technological restraints. The Initial Operating Capability will be gradually augmented in progressing stages beyond about 1995. The later configurations are referred to as the Evolutionary Capability.

The MSS will play the predominant role in satisfying the following functions:

(a) Servicing of attached (external) payloads
(b) Space Station assembly
(c) Space Station maintenance (external)
(d) Transport on Space Station
(e) Deployment and retrieval functions
(f) Support to external vehicular activities (EVA) of astronauts

The configuration and elements of the Mobile Servicing System, as envisaged in June 1986, are depicted in Figures 2 and 3. As the Program is still evolving, these are subject to continuing revision.

The technologies needed for the design and development of the Mobile Servicing System are described below. Owing to the complex interdependence between them, small gaps and overlaps in the definitions are inevitable.

TELEOPERATORS AND ROBOTICS

A goal in the Space Station Program is to keep the need for astronaut extra-vehicular activity (EVA) to a minimum, as it requires substantial operational support and is of higher risk than desirable. The goal will be accomplished through the use of mobile manipulators that are teleoperable from the pressurized modules, by automation of the manipulator functions to the maximum extent possible, and through use of additional robots in the form of special end effectors and dextrous manipulators. The following are the subtechnologies of teleoperation and robotics, in the context of the MSS.

Vision Systems

Computer vision is the process of producing useful symbolic descriptions of a visual environment from image data. It provides information about what objects are present in the environment and it can also detect motion. Advanced systems would be capable of recognition, inspection, and interpretation.

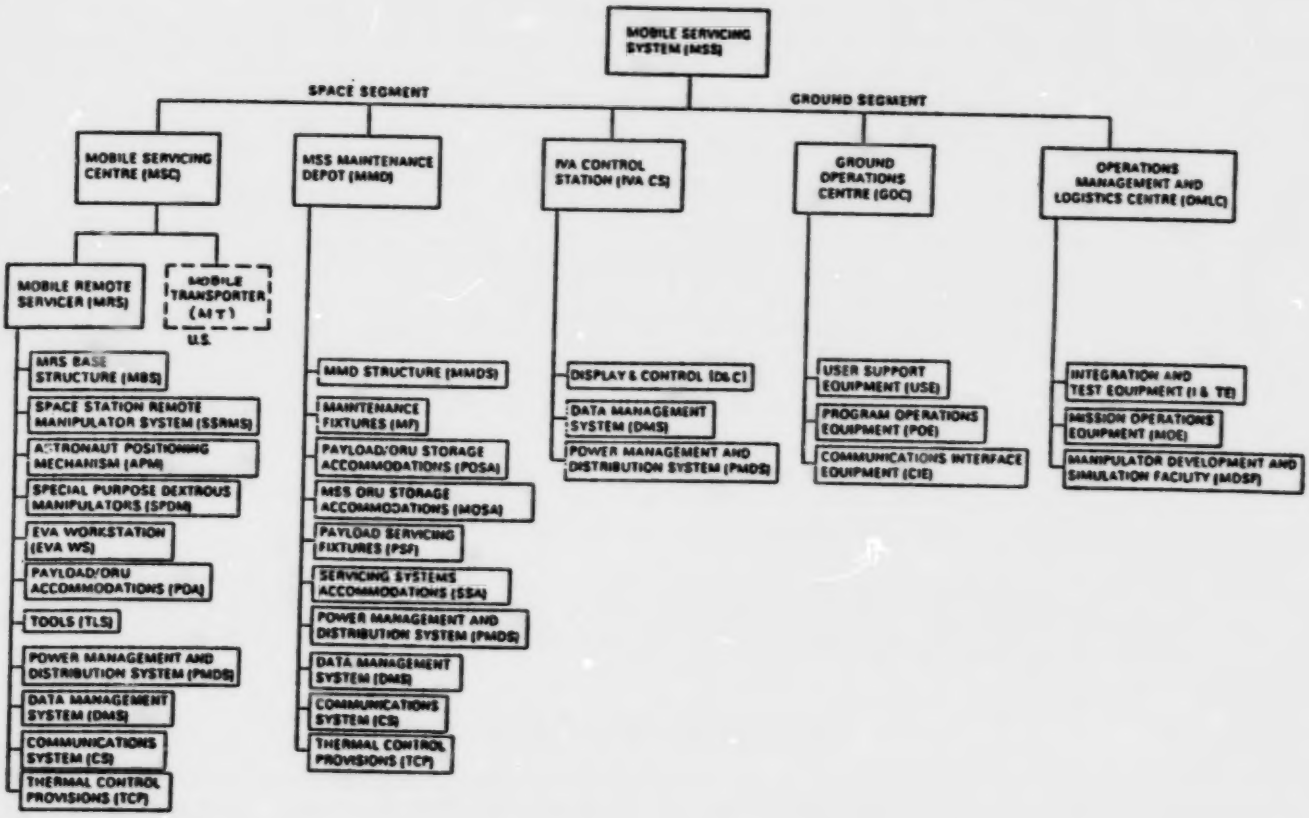
MOBILE SERVICING SYSTEM (MSS)
SPACE SEGMENT
GROUND SEGMENT
MOBILE SERVICING CENTRE (MSC)
MSS MAINTENANCE DEPOT (MMD)
IVA CONTROL STATION (IVA CS)
GROUND OPERATIONS CENTRE (GOC)
OPERATIONS MANAGEMENT AND LOGISTICS CENTRE (OMLC)
MOBILE REMOTE SERVICER (MRS)
MOBILE TRANSPORTER (MT)
U.S.
MRS BASE STRUCTURE (MBS)
SPACE STATION REMOTE MANIPULATOR SYSTEM (SSRMS)
ASTRONAUT POSITIONING MECHANISM (APM)
SPECIAL PURPOSE DEXTROUS MANIPULATORS (SPDM)
EVA WORKSTATION (EVA WS)
PAYLOAD/ORU ACCOMMODATIONS (PDA)
TOOLS (TLS)
POWER MANAGEMENT AND DISTRIBUTION SYSTEM (PMDS)
DATA MANAGEMENT SYSTEM (DMS)
COMMUNICATIONS SYSTEM (CS)
THERMAL CONTROL PROVISIONS (TCP)
MMD STRUCTURE (MMDS)
MAINTENANCE FIXTURES (MF)
PAYLOAD/ORU STORAGE ACCOMMODATIONS (POSA)
MSS ORU STORAGE ACCOMMODATIONS (MOSA)
PAYLOAD SERVICING FIXTURES (PSF)
SERVICING SYSTEMS ACCOMMODATIONS (SSA)
POWER MANAGEMENT AND DISTRIBUTION SYSTEM (PMDS)
DATA MANAGEMENT SYSTEM (DMS)
COMMUNICATIONS SYSTEM (CS)
THERMAL CONTROL PROVISIONS (TCP)
DISPLAY & CONTROL (D&C)
DATA MANAGEMENT SYSTEM (DMS)
POWER MANAGEMENT AND DISTRIBUTION SYSTEM (PMDS)
USER SUPPORT EQUIPMENT (USE)
PROGRAM OPERATIONS EQUIPMENT (POE)
COMMUNICATIONS INTERFACE EQUIPMENT (CIE)
INTEGRATION AND TEST EQUIPMENT (I & TE)
MISSION OPERATIONS EQUIPMENT (MOE)
MANIPULATOR DEVELOPMENT AND SIMULATION FACILITY (MDSF)

Figure 1. Mobile Servicing System Hierarchy

(as of June 1986)

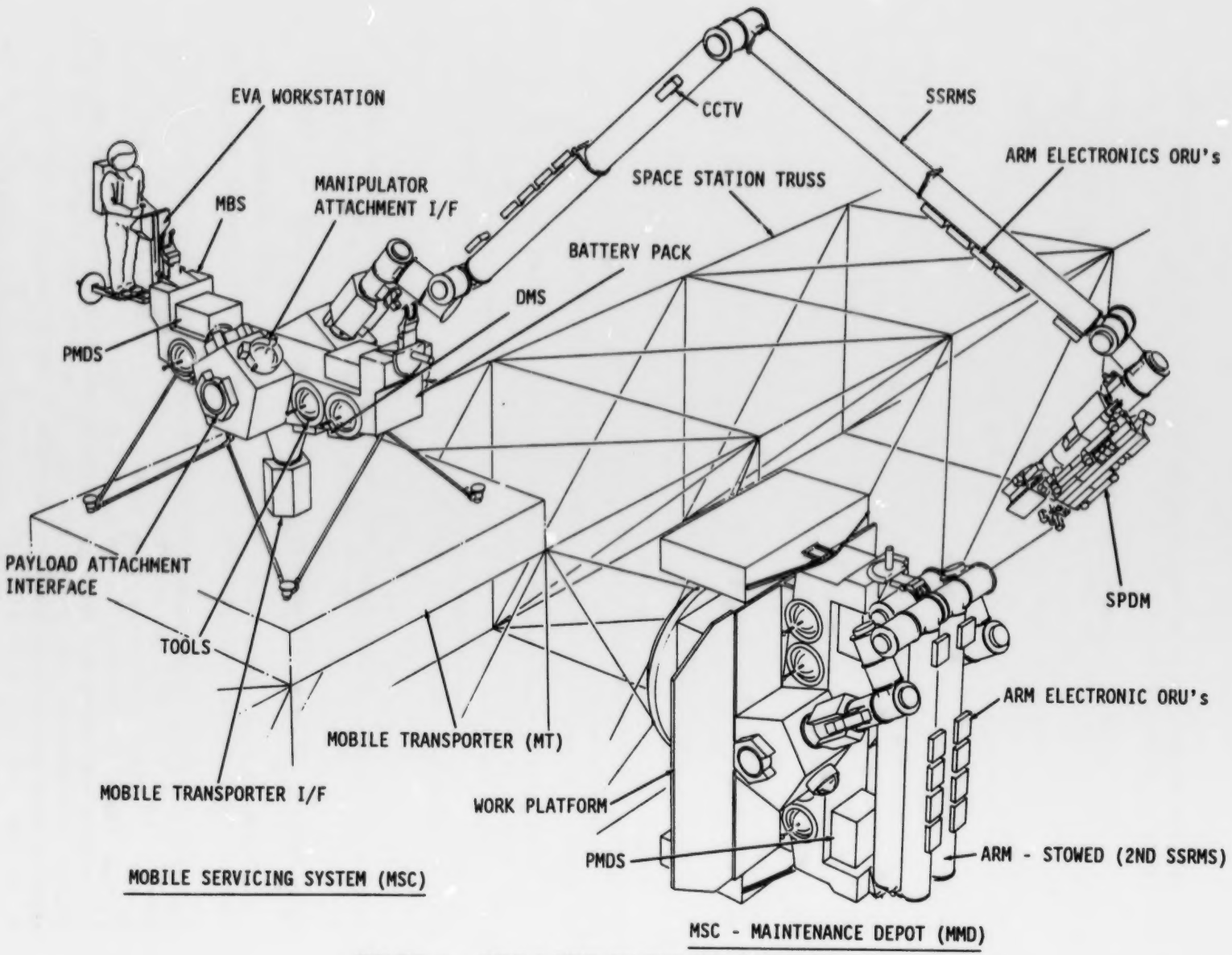

FIGURE 2 MSC & MMD ON THE SPACE STATION

Vision systems require the subtechnologies of optical sensing, image processing, feature extraction and recognition, and illumination design.

The MSS vision system to be developed will be used for collision detection and avoidance (to detect the presence of obstacles so that the manipulator can go around them without hitting them), automatic payload capturing (to detect the position and orientation of a payload so that the manipulator can capture it automatically), detection of unexpected objects in the environment and warning provision, and inspection of payloads.

Sensors

The MSS will use a variety of sensors. These will include TV cameras for Vision Systems as well as overall task monitoring, joint position sensors and rate sensors. Other sensing techniques may need to be developed for collision detection. Force/torque sensors and tactile sensors will be needed for manipulator control and end effectors.

Robot Programming

Robot programming includes R&D on appropriate languages, compututional architectures and algorithms for command and control.

Robot programming requires research and development in two primary areas, for the MSS. First, a robot command structure must be defined that will accommodate a high level of command. Second, the software must allow abstracts to be used so that any manipulator configuration can be programmed.

The robot command language defines the task or command for the MSS such that the task/command definitions are independent of the particular manipulator configuration, and the introduction of new tasks/commands is easy and convenient. The hierarchy of the commands from the task level to the manipulator joint command level must be established.

To develop the software technology which allows abstraction involves studies of 'object based computing' techniques. These techniques include using data as an abstraction or using a program as an abstraction.

Human-Machine Interfaces/Telepresence

Human-machine interfaces entail considering and maximizing the 'friendliness' of the robot machine to use by an operator.

In the MSS, a 'friendly' operating environment may include speech input/output (i.e. dialogue with the MSS), touch screen input (i.e. point to screen to select procedures from menus) and a knowledge based system to monitor these processes. Feedback to the operator of manipulator forces and torques may be needed for some manipulative tasks. The rate of data and command transmission, the number and type of sensors and displays, and the style of hand controllers are also key factors.

The contextual approach to interfacing (i.e. the adaptation of the machine to the operator's mental process) may also be used to streamline the

input and output sequence. This would entail provision of the following features:

(a) minimize the number of steps to reach target results
(b) present only those controls that can be used in the very next step
(c) optimize effects of inputs for the current mode of operation
(d) offer system generated options/suggestions to the user
(e) permit system's dynamic learning of the current user's preference, cognitive pattern and needs.

'Telepresence' refers to a highly developed level of human-machine interface, whereby a user, when operating a manipulator from a remote location, may develop a sense of being present at the manipulator location. The development of 'telepresence' capabilities in conjunction with the robotics for the Orbital Maneuvering Vehicle (OMV) and spin-offs to terrestrial applications is a major target of US-sponsored R&D in robotics.

Manipulator Analysis

Manipulator analysis comprises mathematical methods and software kinematics, dynamics (including flexibility), and computation.

In the MSS program, this area will include:

(a) The analysis of multibody structures with tree topologies, any number of bodies (articulations), flexible and/or rigid bodies, translational and rotational joints;

(b) User selectable, efficient formulations and solution methods for multibody dynamics;

(c) User selectable model order reduction techniques;

(d) User selectable integration methods for simulations;

(e) Simulation of assembly tasks (constrained motion, contact dynamics); and

(f) Simulation of capture/release of payloads.

Manipulator Control

This area is concerned with the control and control systems aspects of the design and performance of manipulators.

New manipulator control techniques will need to be developed to increase the capabilities of manipulators in space. Such features are:

(a) Force Accommodation -- which is the ability of the control system to sense forces and torques being applied by the end of a manipulator and automatically limit these to pre-set values;

(b) Modeling and multivariable design of control systems for rigid and structurally flexible manipulators;

(c) Multiple Arm Co-ordination -- which is the ability to simultaneously operate more than one manipulator in the task environment;

(d) Automated Collision Detection/Avoidance -- using Vision Systems techniques as well as a "World Model" data base, the MSS will need to detect and avoid collisions with other structures on the Space Shuttle while carrying out its task;

(e) Automated trajectory planning, using artificial intelligence; and

(f) Machine Learning -- using artificial intelligence to enable the MSS to evaluate its performance of control/operation strategy planning, trajectory planning and the execution of operations and to perform these tasks more efficiently. The potential exists for the system to learn, not only how to more effectively deal with recurrent situations and to apply this knowledge to similar problems but also to make its motions more efficient by training its control systems to account for unpredicted hardware characteristics and periodic disturbances.

Simulators

This area includes non-real time and real time simulators (software and hardware facilities) and astronaut training.

To carry out the complex analyses required to design various elements of the MSS (e.g., the manipulator arms) and to be able to display graphically the operational characteristics, a major ground-based simulator, the Manipulator Development and Simulation Facility (MDSF), is being developed.

This facility will also be used, along with a Software Support Environment (SSE) provided by NASA, to develop the flight software and perform hardware/software integration of the MSS. During the operations of the MSS, this facility will form part of the ground-based Operations, Management and Logistics Centre (OMLC). Additionally, an on-orbit simulation capability will be required for crew training, procedure development, etc.

Training for Space Station tasks will consist of ground-based training prior to flight and on-board training for mission-specific tasks. Training facilities will use on-orbit simulation capability. Ground-based and on-orbit data bases will be accessed for task specific training, especially for maintenance. A tutor program with data base will be developed for refresher training.

Robot Mechanisms

Robot mechanisms include tools, end effectors, 'smart' mechanisms, hand controller mechanisms, and joints.

Tools and end effectors are the working end of remote manipulators, large or small, that may be used to perform the servicing, maintenance, docking and retrieval functions on the MSS. Tools are more specific to the task, while the end effectors are more general-purpose mechanisms. The tools are the interchangeable elements of the servicing system. Tools will probably be in a state of evolution for some time, as a consequence of the need to adapt them to tasks which may be evolving.

End effectors are the hands of manipulators which are used to grasp, hold and release in a controlled manner objects that may be as small as a tool, medium sized as a replaceable unit of equipment, or as large as a Space Shuttle. They are correspondingly complex and require considerable design and development work. Being more general-purpose than tools, a lower cost may be achieved by devising and producing in larger numbers of a standard type.

'Smart' mechanisms would typically be end effectors capable of grasping and holding both moving and stationary objects, mechanisms that simulate the actions of a human hand or a human arm and, at a lower level of sophistication, devices that are specialized towards performing, with great efficiency, despite constraints of space, size and weight, simple tasks of holding, releasing, moving, positioning and fastening. Smart mechanisms are typically driven by electrical motors and are sequenced by electronics and/or computers. The main characteristics of smart mechanisms (in addition to the performance of their tasks) are: reliability, high strength and stiffness relative to their own weight, low rates of wear, use of lubricants for space application (vacuum) and high levels of tolerance to often large differences in temperatures and temperature gradients.

AUTOMATION OF OPERATIONS

A further goal in the Space Station Program is to automate housekeeping and other operations to the maximum extent possible, to attain autonomy of the Station in orbit and reduce ground control requirements. This will be achieved through comprehensive computer-based management systems (in some cases exploiting expert systems and artificial intelligence technologies) that automate operational functions and that raise the level of autonomy of certain components and subsystems. The following are of significance in MSS operations.

Expert Systems in Operations

The procedures for the MSS mission operations will be modularized in manageable segments and made a part of an on-orbit data base. Artificial Intelligence programs will be able to help crew put together mission procedures in non-real time and perform the validity checks using an on-orbit simulation system. The system will be designed to accumulate a knowledge base as these modularized procedures are used, eventually leading to an automated mission procedures recommendation by the data base.

Present manned space operations are supported by armies of experts on the ground providing backup support for 24 hours each day to the astronauts.

This will not be cost effective for Space Station with its proposed indefinite lifetime and continual habitation. The expertise and support provided by the ground will have to be reduced so that Station is much more autonomous than the Space Shuttle. This means that ground expertise will need to be automated in some way. Knowledge-based expert systems and artificial intelligence offer the means to automate the knowledge used to support the Station. Areas of application would include malfunction handling and fault diagnosis, planning and scheduling under constraints.

Automated Data Management

Command and control of the MSS will be achieved from internal work stations located in a shirt-sleeve environment in Space Station and from an external work station located on the MSS itself. The MSS will contain many sensors (TV cameras, joint position and rate sensors, force and torque sensors, etc.), and actuators (arm joints, end effectors, tools etc.). The data to and from these will need to be coordinated and organized in an efficient manner. Data will be transmitted both over data busses and via RF links and will be managed by computers - forming an automated data management system.

Automated Power Management

The operational duty cycle of the MSS will be quite complex considering its need for translation along the Station structure, manipulation of large payloads and servicing of attached payloads. The orbital rate (frequent eclipse and sunlight periods) also causes fluctations in thermal control system demands. Housekeeping power will be a limited resource on Station, requiring the MSS to manage and control its power consumption optimally. This will require a computerized, automated load management and distribution system.

For Space Station, it is envisaged that the power system would be capable of acting autonomously, responding to Station or ground-originated stimuli, or being overidden by ground command. The primary functions of the automated system are power systems and user loads management, detection and correction of power system faults, and assessment of power system performance. Secondary functions are to maximize the quantity of information on performance, and minimize the quantity of telemetry channels needed. The automated power system for the basic MSS will likely use conventional techniques. For the evolutionary Space Station, NASA plans to use a mix of conventional and Artificial Intelligence techniques. For the evolutionary MSS, Expert System technology is likely to be employed.

ELECTRICAL AND ELECTRONICS

Processing System and Interprocessor Communications

This area includes the technologies involved in the design and development of the system needed to perform the MSS teleoperation and robotics functions and the data management functions.

The MSS processing system consists of operating system software (e.g. task scheduling, interrupt handling, fault management), hardware (e.g. processing units, interprocessor communications and input/output interfaces), and application software (e.g. manipulator algorithms).

The technology areas involved in the design of such a system include microelectronics (VLSI, etc.), distributed processing (multiprocessing and networking), fault-tolerant computing (hardware and software associated with fault detection, identification and recovery), and software engineering (layered software, object oriented design, reliable software development). The implementation of expert systems, natural language processing, vision systems, and knowledge engineering are also factors that influence the design of processing systems.

It is anticipated that NASA will specify a standard or common processor and data bus system for the Space Station and a common software language.

Communications

Communications between the MSS and the Space Station is planned to be via an RF link. The link will have to support a data rate commensurate with a 'telepresence' level of man-machine interface, and will have to be functional for all locations of the MSS on the Station.

Power Systems

This area includes power system design, power sources and storage devices, load converters, and other components.

The MSS will receive power from Space Station. Long life batteries (possibly Nickel-Hydrogen batteries) will also be required. New load converters, remote bus isolators, and remote power controllers are envisaged. The development of a high power, high efficiency, minimum mass and volume load converter to fit in the relocatable arm will demand the use of state-of-the art electronics.

STRUCTURES AND MATERIALS

Structural Design

This area includes structures design and development, including computer-aided engineering and design (finite element modeling, loads and vibration analysis, etc.).

Weight and volume will be at a premium due to launch costs and constraints, and hence the structure of the MSS will necessarily be an optimal lightweight design.

Long-Life Lubrication

Upgrading of existing space lubricant systems will be necessary to meet the life requirements for the MSS. It is anticipated that changes to solid

lubricant application procedures will be required and possibly different solid or liquid lubricant systems will be developed. Verification of the life and performance of both gears and bearings will be necessary following changes in the lubricant procedures and/or systems. Similarly, the life expectancy of parts lubricated with grease will require reviewing with any changes being supported by testing.

Materials

High strength-to-mass and high stiffness-to-mass materials, e.g. carbon composites and Kevlar, will likely be needed for structures fabrication due to a requirement to minimize weight at launch. In addition, advanced materials must exhibit corrosion resistance, so that humidity in the pre-launch phase should not lead to formation of contaminants and potential debris in space, lack of sensitivity to damage and capability to sustain potentially large differences (in range and gradients) of temperatures when in vacuum.

Performance of brakes and clutches used on space mechanisms depends primarily on the ability of the friction lining material to retain its characteristics in the space environment. Periodic loss and recovery of brake slip torque values have been noted on space mechanisms in vacuum tests. Recovery takes place on returning to ambient pressures. Returning to ambient pressure, however, is not feasible for the Mobile Service Centre and therefore new friction material will be necessary. Testing to determine performance characteristics and life will be essential.

Thermal Control

State-of-the-art thermal control techniques and materials to minimize the constraints imposed by temperature control considerations will be required. This will include passive thermal control techniques, from surface treatments to the use of fins, radiators, doublers, etc. Materials such as multi-layer insulation, second surface mirrors, tapes, paints, coating processes and electrical skin heaters will be used. Where this is not sufficient, active thermal control may be employed in the form of heat pipes, louvres or fluid loops.

The selection and use of the above materials is constrained by environmental considerations which include degradation from UV, atomic oxygen, meteorites and electrostatic charges. The latter poses special risks for electronic equipment and telemetry/communications, and to prevent it involves ensuring external surface electrical conductivity and grounding, or the use of materials proven suitable through testing.

Environmental Effects

This area comprises the knowledge base for the understanding of the physics of atomic oxygen, radiation, and electrical charging, on the materials and components of the MSS.

VERIFICATION

Qualification Strategies

Complete system testing in a one-g environment is not possible for major elements of the MSS (e.g. the large manipulators). The system (hardware and software) will be 'qualified', i.e. certified to be operational by a combination of ground-based analyses, simulations, component and subsystem ground tests, and on-orbit testing.

Reliability and Quality Assurance

This area includes reliability engineering and destructive and non-destructive test of devices.

Integration and Test

The integration and test facilities and methods in Canada (mainly at DFL and SPAR-Ormont) were originally developed to accommodate communications satellites and the Canadarm. New or upgraded methods and facilities may be needed for MSS.

Automated Test Equipment

The technology/design will be developed such that the following capabilities can be incorporated into flight hardware "Black Boxes":

(a) Auto data dump on demand of "Health and Status";
(b) Built-in test and calibration capability from initial build to operation;
(c) Self healing based on failure analysis and knowledge based decisions;
(d) Degradation measurement/failure record; and
(e) Load interaction and health sense of remote loads.

Test equipment both on the ground and on-orbit will take advantage of these "black box" capabilities to perform automated health check, fault isolation and diagnostics.

Software Development and Verification

This area encompasses software methodologies and includes software development, software standards, control and verification.

The standards and verification procedures of software for MSS are likely to be influenced strongly by NASA. The form (version) of ADA and the verification procedures will entail substantial innovation and development.

For a software system as complex as that required for the MSS and with substantial requirements for continued evolution, it is essential that advanced configuration control techniques be implemented and that the use of 5th generation languages for software development be investigated. Software development tools based on this technology can be made to virtually automate

the production of software. New developments such may be foreseen that give the capability to:

- write essentially error free code, adhering to predefined standards;
- manage and reconfigure the software package consistent localized changes; and
- prototype and simulate the operational software prior to actually writing it.

APPENDIX B

Questionnaire

[Please submit by 30 November 1986]

Part I -- Technology Development

The next page lists 21 selected technologies relevant to Space Station. Six brief questions are asked about each of these technologies. For explanations of what is meant by each of the 21 technologies, please see the "Glossary of Space Station Technologies." For guidance on what is meant by each of the six questions, please see the "Guide to Questions in Part I." Are there other technologies, not on the list, that your organization feels are relevant? If so, please add them to the list.

Part II -- Technology Transfer

Are there mechanisms you would like to see implemented for achieving technology development and transfer? Please comment.

We would appreciate your remarks on any other aspect of the strategy that Canada should adopt to ensure technology development and technology transfer with respect to the Space Station project.

Does your organization wish to be kept on the mailing list of the Space Station Advanced Technology Subcommittee?

Yes ☐ No ☐

If so, who is the most appropriate contact in your organization? [Please supply complete name and address.]

[See Glossary of Space Station Technologies, and Guide to Questions.]

IRRELEVANT TO MY ORGANIZATION	OF INTEREST TO MY ORGANIZATION	CRITICAL TO MY ORGANIZATION	CANADA AT WORLD STANDARD	CAN FORESEE RAPID EVOLUTION	CRITICAL TO CANADA	
☐	☐	☐	☐	☐	☐	Astronaut Training
☐	☐	☐	☐	☐	☐	Automated Data Management
☐	☐	☐	☐	☐	☐	Automated Power Management
☐	☐	☐	☐	☐	☐	Automated Test Equipment
☐	☐	☐	☐	☐	☐	Expert Systems
☐	☐	☐	☐	☐	☐	Long-Life Brake/Clutch Materials
☐	☐	☐	☐	☐	☐	Long-Life Lubrication
☐	☐	☐	☐	☐	☐	Manipulator Analysis
☐	☐	☐	☐	☐	☐	Manipulator Control
☐	☐	☐	☐	☐	☐	Man-Machine Interfaces
☐	☐	☐	☐	☐	☐	Materials & Structures
☐	☐	☐	☐	☐	☐	Mission Operations
☐	☐	☐	☐	☐	☐	Processors & Data Busses
☐	☐	☐	☐	☐	☐	Qualification (Incl. In-Orbit Test)
☐	☐	☐	☐	☐	☐	Robot Programming
☐	☐	☐	☐	☐	☐	Sensors
☐	☐	☐	☐	☐	☐	Simulators
☐	☐	☐	☐	☐	☐	"Smart" Mechanisms
☐	☐	☐	☐	☐	☐	Thermal Control
☐	☐	☐	☐	☐	☐	Tools & End Effectors
☐	☐	☐	☐	☐	☐	Vision Systems

GUIDE TO QUESTIONS IN PART I

☐ "IRRELEVANT TO MY ORGANIZATION"

☐ "OF INTEREST TO MY ORGANIZATION"

☐ "CRITICAL TO MY ORGANIZATION"

Only one of the three boxes should be checked. These questions solicit your evaluation of the importance of each technology insofar as the goals and plans of your organization are concerned.

☐ "CANADA AT WORLD STANDARD"

This and the next two questions solicit your evaluation of the national importance of each technology. This question, in particular, asks whether Canada's technology in this area is, in your opinion, at or near the international standard. [A checked box means "Yes"; an unchecked box means either "No," or "No Opinion."]

☐ "CAN FORESEE RAPID EVOLUTION"

A check in this box means that there will, in your opinion, be rapid evolution of this technology over the next 5-10 years.

☐ "CRITICAL TO CANADA"

This question asks for your evaluation of the overall strategic importance of this technology to Canada. This evaluation should take into account not only Canada's current world position in, and rate of development of, this technology (see previous two questions), but also its spin-off potential and its importance in penetrating world markets.

APPENDIX C

MAILING LIST FOR QUESTIONNAIRE

Allied Signals Canada
Andrew Antenna Company Limited
Barringer Research Limited
Bell Northern Research
Bird and Hale Limited
Canadian Artificial Intelligence Products
Canadian Astronautics Limited
Canadian Marconi Co.
Certelecom Laboratories Inc.
Collins and Moon Limited
ComDev Limited
Crossfield Muirhead Inc.
Golder Associates
Gregory Geoscience Limited
Havlik Technologies Inc.
High Vacuum Systems Inc.
Honeywell Limited
Horler Information Inc.
Hunter and Associates
IFR Associates
Interactive Circuits and Systems Limited
Intercon Consultants
Kirk Satellite Communications
KVA Communications and Electronics Company
Lavalin-Fanco Engineers Inc.
Leigh Instruments Limited
Lindsay Specialty Products
Linear Technology Inc.
Litton Systems Canada Limited
MA Electronics Canada Limited
Marinav Canada Inc.
Marshall Macklin Monaqham Limited
Martin Marietta Canada Limited
Miller Communications Systems Limited
Moniteq Limited
Motorola Canada Inc.
M.R. Byrne & Associates
Muirhead Systems Limited
Optech Inc.
Optotek Limited
Perceptron Computing Inc.
Philip A. Lapp Limited
Prendergast Communications Inc.
Project Research Group Limited
QRL Analysis Corp.
Raytheon Canada Limited
Reltek Incorporated
Robinson, Merritt and deVries Limited

(cont'd)

Robotic Systems International
Rockwell International of Canada Limited
Roy Ball Associates
Roy M. Dohoo Limited
saTel Consultants Limited
Scientific Atlanta Canada Limited
SCS Consultants Incorporated
SHL Graphics Systems Limited
Sinclair Radio Laboratories
Skyswitch Satellite Communications Corp.
SkyWave Electronics Limited
Spar Aerospace Limited
Sparton of Canada Limited
Spectral Digital Services Inc.
Telesat Canada
Telespace Information Limited
TIW systems Ltd.
Triple Crown Electrnics Incorporated
TYDAC Technologies Incorporated
Valcom Limited
Varian Canada Inc.
Trainor Surveys
Universal Systems Limited
NORDCO
Boeing Fabrication & Services Company of Canada
Bristol Aerospace Limited
Dendron Resource Surveys Ltd.
Dipix Limited
Euroline Inc.
Fleet Industries Limited
Garratt Manufacturing Ltd.
KVA Communications & Electronics Co.
MacDonald, Dettweiler & Associates
Maya Heat Transfer Technologies Ltd.
Motorola Information Systems
PAMAP Graphics Ltd.
SED Systems Inc.
Teledetection International
CAE Electronics Ltd.
MARS Aerial Remote Sensing Limited
COV-CAN Control Systems Limited
General Systems Research Limited
Hardy Associates Limited
Intera Technologies
Itres Research Limited
Jensen Engineering Incorporated
Nortech Surveys (Canada) Incorporated
ADGA Group
AIT Advanced Information Technologies Corporation
ANCON Space Technology Corporation